CONFERENCE OF THE EIGHTEEN-NATION COMMITTEE
ON DISARMAMENT

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MEMORANDUM

on the control of an underground test ban treaty.

1. Purpose

The purpose of this document is to provide a more detailed explanation of the scientific background to some of the statements on the problems of underground test ban control, made by the Representative of Sweden in the ENDC on June 29, 1967 (ENDC/PV.309). To make it more generally accessible, descriptive language has been used. To be fully understandable some of the points would, however, require an explanation in mathematical terms.

As stated in the speech, the Swedish investigations have been concentrated on the question of how to use seismological methods of identification to distinguish underground explosions among earthquakes for the purpose of verifying an underground test ban treaty.

2. Analytical method used

The statistical method of evaluation employed constitutes an application of decision theory and is a further development of the method described in a report from the National Defence Research Institute in Stockholm[1/]. It has been used to evaluate both the case of control with inspection and the case of such control without inspection.

The basic assumption made was that a convincing control system would have to satisfy two political requirements:

(1) It should provide sufficient deterrence against violations by making the probability for discovery sufficiently high;

(2) It should contain adequate assurance against the risk that "freaks of nature", in the form of earthquakes similar in appearance to explosions, should induce unwarranted political accusations.

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1/ Approaches to some test ban control problems, National Defence Research Institute, Stockholm Report C 4286 - 20(23) 1967

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These political requirements were put into mathematical form together with the statistical properties of the identification method investigated. The quantities obtained were then used in a mathematical model of control procedures which takes into account the always present risks of mistaking explosions for earthquakes and vice versa. (The appearance now and then of explosions looking like earthquakes is covered in this way). This model then provides a procedure by which to determine the level of earthquake similarity below which an event is regarded as an explosion. This level is selected in such a way as to provide the required deterrence against violations and at the same time providing sufficient assurance against mistakes concerning earthquakes. An essential feature of the method employed is that it also permits the determination of the most efficient level of earthquake-similarity, efficient in the sense that the required deterrent is maintained at the same time as - in the non-inspection case - the risk for mistakes concerning earthquakes is made as small as possible. Likewise, in the inspection case, the number of inspections required is minimized.

In conclusion, the method employed provides a procedure to determine whether a particular identification method, exploited in the most efficient way, meets a particular political control requirement or not.

3. Specific assumptions

The method involves eight basic quantities. These are described more fully in the following. In order to be able to make the calculations, specific numerical values have been assigned to some of them. This is also explained below.

For three of the eight quantities the numerical values are determined by nature and by the observational techniques available.

For the purpose of calculation, the number of earthquakes per year in the area to be monitored was taken as 200. According to an official statement in the United States[2] this corresponds to the yearly number of shallow earthquakes in the Soviet Union, of magnitudes larger than 4. This number has also been said to be not far from the corresponding number of earthquakes in the United States. The particular magnitude level of 4 was selected as being close to the level of routine detection by the powerful seismological LASA station in Montana. Events of magnitudes just above this detection level will, because of the sophisticated post detection processing possible with data from this station, have a signal to noise ratio which is helpful to identification analysis also of these weak events. The magnitude corresponds to underground explosions in hard rock of nuclear devices with yields of approximately one kiloton.

Two statistical quantities were employed to describe the particular identification methods considered. One of them is determined by the physical properties of earthquakes and the other by the corresponding properties of explosions. Both are influenced by the particular method of measurement employed. In all, five identification methods were studied. The statistical properties of these various methods were obtained from published reports or from articles in scientific journals. Three of them[3] make use of local or regional data, measured within approximately 1000 km from the event. (For the purpose of test ban control such regional data could be obtained through a proper international data exchange.) The two

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2/ US Congress, Hearings on Developments in Technical Capabilities for Detecting and Identifying Nuclear Weapon Tests, March 1963.

3/ J. Brune, A. Espinosa and J. Oliver
Journal of Geophysical Research, June 1, 1963, p.3501-3513

E. Jebe and D. Willis
Earthquake Notes, September-October 1964, p.28-40

A. Brooker and W. Mitronovas
Bulletin of the Seismological Society of America,
Volume 54, 1964, p.961-971.

other identification methods considered[4/] employ teleseismic data, obtained at distances between 2000 and 10000 km from the event. (These can thus be used over intercontinental distances.)

The remaining five quantities involved in our analysis express the political requirements of the control procedure. Their numerical determination is largely a matter of political and technical judgement and should be considered as a major step in the definition of a control system.

The sufficient deterrence against violations is defined by two quantities: the number of explosions per year in violation of a treaty and a sufficiently high probability of disclosure of such violations. In our calculations the number of these explosions was chosen to be one per year. The disclosure probability level was put at 10 per cent, meaning that a prospective violator would have to face one chance in ten of being disclosed. This level was estimated to be high enough to deter from violations in view of the high political costs involved in a disclosure. As a matter of fact, this figure seems to have been used in similar calculations in the United States. It should not be confused with the higher levels of disclosure desirable in intelligence activities, where one, of course, wants to find out as much as possible.

The second political requirement of the control system, as outlined in the Swedish speech, concerns the adequate assurance against the risk that earthquakes, similar in appearance to explosions, could lead to unwarranted political accusations.

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4/ E.J. Kelly
Semiannual Technical Summary report on Seismic Discrimination,
31 December 1966, Lincoln Laboratory, Lexington, Mass.

P.D. Marshall, E.W. Carpenter, A. Douglas and J.B. Young
Atomic Weapons Research Establishment report No.O-67/66,
Aldermaston, Berks, UK, October 1966.

In the case of control with inspection the process of verification contains two steps. In the first one mistakes concerning earthquakes on the basis of seismological and collateral evidence are of limited importance as the final political decision will be made only after that the second step, that of inspection, has given conclusive evidence of a violation. The case of control with on-site inspection therefore has to take into account the number of such inspections required or permitted. At the outset of our calculations this number was left open as a quantity to be determined by the calculation. In the inspection case the efficiency of inspections also has to be taken into account. This will depend on the inspection procedure provided in the treaty (in past test ban discussions referred to as inspection modalities) and on available techniques for event localization and on-site inspection. This inspection efficiency was taken into account in terms of the probability that inspections of violations will be successful. This probability was put at 50 per cent, being an estimate of what event location capabilities and modalities could provide, taken together.

In the case of control without on-site inspections, the guarantee given by the inspections against mistaking in the final assessment earthquakes for explosions does not exist and has to be replaced by an extremely low probability for making such mistakes. This probability is measured by the expected number of years between such mistakes. In our calculations this number was left open as a quantity to be determined. In assessing the results, we assumed that control systems, where such mistakes are expected to occur only once in a hundred years, are acceptable and that systems with one mistake in ten years are worth being discussed.

4. Results

Using the assumptions described above the calculations showed that some of the identification methods that have been published are of rather limited efficiency. However, data on the British teleseismic or long distance method of identification by complexity, as presented by Kelly in the report referred to in an earlier footnote and obtained with the LASA station in Montana, indicate the

possibility of a control system with no more than one on-site inspection in two years. A similar number of on-site inspections would be sufficient if regional data, proper to the identification method developed in the United States by Booker and Mitronovas and also referred to above, could be obtained, for instance, through an international data exchange. If combined, these two methods should result in a further decrease in the number of on-site inspections required. This constitutes considerable progress if compared with the requirement of several inspections per year stated in the past.

The efficiency of the published identification methods has indeed improved so much during the last years that it has become meaningful to discuss the possibilities for control without inspection. The data on identification by complexity, already referred to, indicate the possibility of an inspection-free control system with the required ten per cent deterrence level and limiting mistakes concerning earthquakes to once in 15 years. This might constitute an acceptable system in itself. It would be further improved if regional data for the Booker and Mitronovas identification method were made available through an international data exchange.

The most promising of the published identification methods is, however, one which makes use of certain simultaneous measurements, from long distances, of long period and short period waves. The value of this method was recognized at an early stage by British scientists and the data on this method, published by Marshall et al. in the British report referred to earlier, indicate the possibility of an inspection-free system operating at a deterrence level of more than 10 per cent and limiting mistakes concerning earthquakes to one in a hundred years. This would be a very impressive system but in this case our estimates rest on rather few observations and one should be cautious in using our conclusions until more data have been made available. To include in its practical application sufficiently low magnitudes this short period/long period method of identification requires that the sensitive short period array stations are combined with arrays of very sensitive long period instruments and powerful computers.